

RESPONSES OF MARINE ORGANISMS DURING THE SOLAR ECLIPSE OF JULY 1963

By BERNARD E. SKUD, *Fishery Biologist*
BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY
BOOTHBAY HARBOR, MAINE 04575

ABSTRACT

Biological and physical observations and measurements were made on the day before and on the day of a total eclipse of the sun, July 19–20, 1963. Totality occurred at 1745 hours (e.d.t.), and observations continued through sunset on both days and in two locations—Bar Harbor and Boothbay Harbor, Maine. Plankton was collected at half-hour intervals, and the activity of herring (*Clupea harengus harengus*) and green crabs (*Carcinus maenas*) was recorded every 15 minutes. Collections of physical data included surface and subsurface illuminance, air and water temperature, salinity, barometric pressure, cloud cover, visibility, and tidal data.

At totality and sunset, the volumes of zooplankton in the surface waters decreased. The responses of copepods varied with the species. *Pseudocalanus minutus* and *Acartia*

longiremis showed the most pronounced response and moved towards the surface. Females of *Acartia* were more active than the males. The reactions of other zooplankters were either weak or ill-defined. Herring began schooling near the surface at totality; this behavior, though not as strong, was comparable to that observed at sunset. Green crabs were not active during the eclipse, but were very active after sunset. Similarly, strong echo-tracings were documented after sunset but none were recorded at totality. Apparently the duration of the eclipse was too short or the light intensity too high, or both, to elicit responses from some organisms.

Observations from earlier eclipse studies of marine organisms are discussed and comparisons are made with other field and laboratory studies of behavior in relation to environmental changes.

Animal behavior during solar eclipses has attracted the interest of scientists and naturalists, alike, but relatively few observations of aquatic organisms, particularly marine animals, have been published. A discussion of this lack at a meeting of the Oceanographic Committee of the National Academy of Sciences in 1962 provided the impetus to undertake the observations reported in this paper.

The few specific references to aquatic observations during solar eclipses generally failed to include adequate definition of the physical conditions. Wheeler, MacCoy, Griscom, Allen, and Coolidge (1935) reported on the behavior of fishes and amphibians as observed by game wardens and the interested public during the eclipse of 1932 in the United States. These reports included remarks about feeding habits of freshwater "trout" and "minnows," responses to angling lures, and unusual activity such as pickerel jumping out of the water, and a goldfish eating the tail of another in an

aquarium. E. E. Dissell (personal communication, Portland, Maine) reported that a school of pollock (*Pollachius virens*) surfaced during the 1932 eclipse—the earliest observation I located for a marine fish. Some of these reports suggest a suppression of activity at totality and others an increased level of activity; but most of the reports were casual observations by laymen and the significance of the observations is limited.

Probably the first carefully planned series of observations was made by Mori (1939), during the 1936 eclipse in Japan. He studied the responses of insects and birds at totality and mentioned the behavior of the sandhopper, *Orchestia* sp., and the migration of eye pigment in the crayfish, *Cambaroides japonicus*. He also included a brief reference to responses of other crustaceans and several fishes. Weber (1952), though mostly concerned with terrestrial organisms, concentrated his efforts on species whose normal behavior was well known and recorded changes in temperature, light, and

humidity during a 1952 eclipse in Iraq. Petipa (1955) sampled zooplankton during the 1954 eclipse in the Black Sea, U.S.S.R., and reported that most of these organisms responded by rising towards the surface at totality. K. F. Wiborg (personal communication, Bergen, Norway) made studies off the Norwegian coast during the 1954 eclipse, but poor weather—overcast with strong winds—hampered the collection of zooplankton and interpretation of results. Some of the observations made during the July 1963 eclipse have already been reported. Skud (1964) recorded the responses of herring, *Clupea harengus*, and the green crab, *Carcinus maenas*; and Backus, Clark, and Wing (1965) described changes in depth of the scattering layers and the occurrence of bioluminescent flashes.

Though the number of references dealing with responses of marine organisms to solar eclipses is small, there is a considerable background of information concerning reactions to light—both in nature and in the laboratory. The purposes of this article are to present the more detailed observations made during the eclipse of July 1963, to compare these observations with pertinent information from similar studies, and to add to the general knowledge of phototactic responses and rhythmic behavior patterns.

OBSERVATIONS AND COLLECTING METHODS

The total eclipse of the sun occurred on Saturday, July 20, 1963, and the path of totality bisected the State of Maine (fig. 1). At Bar Harbor, mid-eclipse occurred at 21:45:00 Ephemeris time (17:44:25 eastern daylight time), the sun's altitude was 25 degrees, the path of totality was 53 miles wide, and the duration was 59 seconds (U.S. Naval Observatory, 1961). All of the State experienced at least 98 percent totality. At totality, cloud cover varied considerably along the coast and obstructed viewing in some areas, as did fog patches in certain offshore areas. At Bar Harbor, the 20-m. Fish and Wildlife Service research vessel *Rorqual* was used as an observation and collecting platform; though a light fog reduced visibility on the water surface to

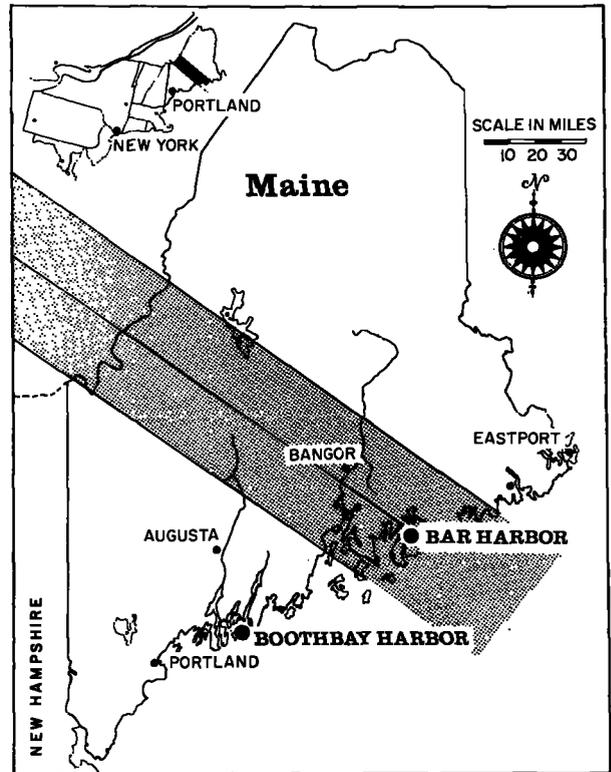


FIGURE 1.—Path of totality and vicinity of sampling areas during solar eclipse of July 20, 1963.

a few miles, the eclipse was fully visible. At Boothbay Harbor, the 14-m. FWS vessel *Phalarope* was used to collect samples. Holding tanks were arranged at the Laboratory dock to study responses of organisms held in captivity. Activity of the captive animals was recorded every 15 minutes. All observations are reported as eastern daylight time unless otherwise specified.

Observations and collections were made on the day previous to the eclipse and on the day of eclipse, beginning at 1600 hours and continuing at intervals through totality (1745) until 2300. The 2-day sequence was intended to provide a test and control in detecting differences in the behavior of animals, as was the extension of observations through sunset and early evening. Light measurements at Boothbay Harbor were made at the surface with a Gossen Lunasix electronic exposure meter.¹ This meter lacked the flat interception

¹Trade names referred to in this publication do not imply endorsement of the products.

screen necessary for precise measurement of illumination, but the incident light readings did provide an index for comparing the illumination between and within days. Aboard the *Rorqual* an irradiance meter (Model C-1a, Marine Advisors, Inc.) equipped with Weston photonic cells measured subsurface changes in light penetration. This unit had a filter with a peak sensitivity of 550 millimicrons and a range of 390 to 760 millimicrons. The irradiance meter provided the ratio of the amount of radiation at the depth of the submerged cell to a reference cell on deck. Secchi-disk readings also were taken at regular intervals. Plankton samples were taken at half-hourly intervals with Miller high-speed samplers at Bar Harbor, and at hourly intervals with the Clarke-Bumpus sampler at Boothbay Harbor. Temperature and salinity were recorded and echo soundings were made continuously during the sampling period.

PHYSICAL CHANGES

Measurements at Boothbay Harbor showed that illuminances on the day before the eclipse were (control day) and the day of the eclipse was not closely comparable (table 1). Except for the period of totality, surface illumination was far greater on the day of the eclipse than on the control day. This difference was also evident from other data. Visibility on July 19 was limited to 9 km., and nine-tenths of the sky was covered by cirrostratus clouds; on July 20, objects were visible at 16 km. and the stratus

cloud cover of seven-tenths was generally dissolving. These differences limited the comparisons which could be made between test and control days.

The decrease in surface illuminance before and at totality and the subsequent increase are documented in table 1. An hour before totality,

TABLE 1.—Surface illuminance at Boothbay Harbor, July 19 and 20, 1963

Time (e.d.t.)	July 19	July 20
	<i>Luxes</i>	<i>Luxes</i>
1546-1600	38,000	>100,000
1601-1615	35,000	>100,000
1616-1630	33,000	>100,000
1631-1645	75,000	75,000
1646-1700	33,000	
1701-1715	64,000	75,000
1716-1730		55,000
1731-1745	24,000	1,900
1746-1800	24,000	1,050
1801-1815	11,500	24,000
1816-1830	9,500	28,000
1831-1845	16,750	19,000
1846-1900	4,800	16,600
1901-1915	3,600	16,600
1916-1930	3,600	3,600
1931-1945	900	825
1946-2000	265	265
2001-2015	110	
2016-2030	20	50
2031-2045	<10	<10
2046-2100	<10	<10

¹ Totality.
² Sunset.

75,000 luxes were recorded, 900 at totality, and 28,000 within the hour after totality. Darkness at totality (1745) approximated that which occurred one-half hour before sunset. Though the primary purpose of Secchi-disk observations was to measure water clarity, the results also provided information on the submarine light penetration during the eclipse. The extinction depth of the Secchi-disk was 7.0 m. at 1600,

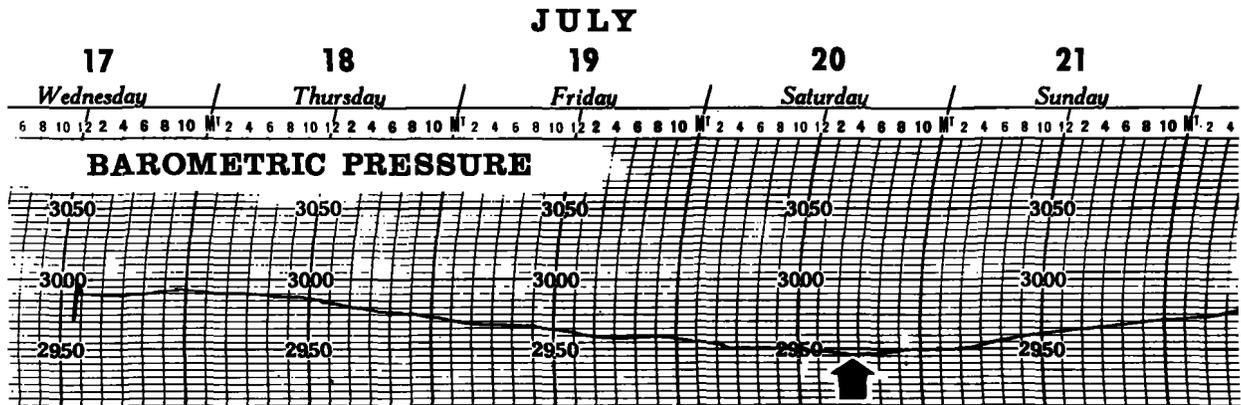


FIGURE 2.—Barometric pressure, mm. of mercury, adjusted to sea level, at Boothbay Harbor. The arrow indicates time of totality.

5.5 m. at totality, 6.0 m. at 1 hour after totality, and 5.5 m. at sunset.

In conjunction with these observations, barometric pressure was measured from Wednesday, July 17 through Sunday, July 21 (fig. 2). Totality coincided with the low pressure read-

ing (29.45 mm.) for the period of observation. The consistent decline in pressure before the eclipse and the rise after totality may or may not be coincidental, but I have been unable to locate similar records from other eclipses.

Observations aboard the *Rorqual* in Bar Harbor were supplemented by land-based observations on Mount Cadillac. LFE Electronics (Boston) conducted a series of tests and supplied me with comparative measurements of a time-light series (fig. 3). The differences among the curves are largely due to the different spectral responses of the photo cells and filters. This information provided an independent comparison of our own measurements with the irradiance meter (table 2). Ten min-

TABLE 2.—Surface and submarine illuminance (luxes) during the eclipse at Bar Harbor, Maine

Depth	Time (e.d.t.)				
	1612	1657	1735 ¹	1804	1840
Surface	36,000	27,800	4,000	4,800	6,200
5	7,600	5,800	800	1,100	1,500
10	2,600	1,500	400	700	500
15	1,100	700	100	200	150
18	500	300	0	100	100

¹ Totality 1745 e.d.t.

utes before totality, the illumination at the surface registered 4,000 luxes, the lowest value in the series of measurements before and after totality. Subsurface values were also lowest at this time. As is evident from these data, the eclipse occurred during a normal period of declining brightness, but the substantial reduction in illumination at or near totality and the subsequent increase clearly distinguishes the influence of the eclipse. During the eclipse, air temperature declined from 15.3° to 12.5° C., and water temperature at the surface declined from 12.8° to 11.3° C. Though the eclipse may have accentuated the temperature change, the late afternoon decline was anticipated. Water temperature at depth remained nearly constant; 1 hour before totality it was 10.3° C. at 10 meters; 9.3° at 20 m.; 8.3° at 30 m.; and 7.8° at 60 m. Salinity ranged from 31.35 to 31.74 ‰ at the surface and from 32.09 to 32.23 at 60 m. These differences in salinity were assumed to be caused by tidal

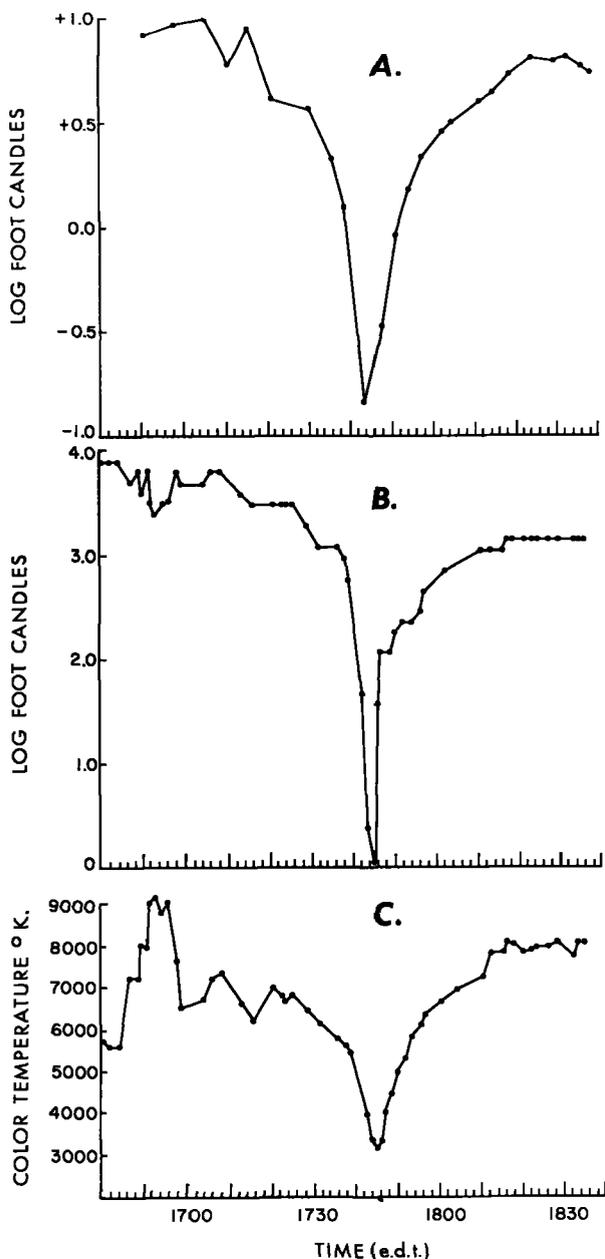


FIGURE 3.—Time-light curve from: A. photometer; B. Gossen light meter; and C. Gossen Sixticolor meter. (One foot-candle = 10.76 luxes.)

movements. Low tide was at 1646 hours and was -0.08 m.; high tide occurred at 2256, and was 4 m. A light fog sometimes hampered vertical visibility but generally did not obscure the sun.

BEHAVIOR OF ZOOPLANKTON

Cladocerans and copepods were the most numerous zooplankton, accounting for more than 90 percent of the plankters. Less abundant groups included gastropods, brachyurans, and decapod larvae, cirriped nauplii, and chaetognaths. Total volumes of zooplankton and the distribution of seven species of copepods were examined to determine any behavioral changes during the eclipse.

Though the light intensity on July 19 was lower and more variable than on the day of the eclipse, this difference did not totally negate the comparison of zooplankton distribution on the test and control days. Miller high-speed samplers (without meters) were used at Bar Harbor; and Clarke-Bumpus samplers (with

meters) at Boothbay Harbor. The zooplankton volumes from surface tows in the two locations are compared in figure 4, along with the changes in light intensity during the 2 days. Although this comparison does not account for amounts of water strained for either gear, the duration of tows in each locale were nearly the same, and the changes in zooplankton abundance which were recorded for the different gears followed similar trends. On both days, the surface volumes of zooplankton decreased at or near sunset and then increased rapidly during the following hour. On the day of the eclipse, a similar decrease was noted at totality, both at Bar Harbor and Boothbay Harbor. This phenomenon was also evident in the quantitative data from the Clarke-Bumpus samplers. Volumes of collections made at the surface were 130 cc./10m.³ an hour before the eclipse, 67 cc./10m.³ at totality, and 105 cc./10m.³ an hour after totality. The decrease in volume also was noted at 20 m.—231 cc./10m.³ an hour before totality, 165 cc./10m.³ at totality, and 222 cc./10m.³ an hour later. At intermediate depths, 3 to 10 m., there was no pronounced change in volume at totality.

The distribution of seven species of copepods differed measurably on both the test and control days and during the period of the eclipse. On July 19, *Pseudocalanus minutus* and *Acartia longiremis* occupied shallower strata of water than on July 20, which was the brighter day. These species also showed the most pronounced response during the eclipse. The upward movement of these two species and the differences in vertical distribution between days are shown in figure 5. The responses of *Centropages hamatus*, *Tortanus discaudatus*, *Calanus finmarchicus*, *Temora longicornis*, and *Eurytemora herdmani* were not as well defined as those of *P. minutus* and *A. longiremis*, and the responses of some species differed at the two sampling locations. For example, the numbers of *C. finmarchicus* and *T. longicornis* from the surface to 10 m. increased during the eclipse at Boothbay Harbor, but declined at Bar Harbor. The abundance of *E. herdmani* was so limited in Bar Harbor that its distribution could not be plotted reliably; in Boothbay Harbor this species was one of the most abundant

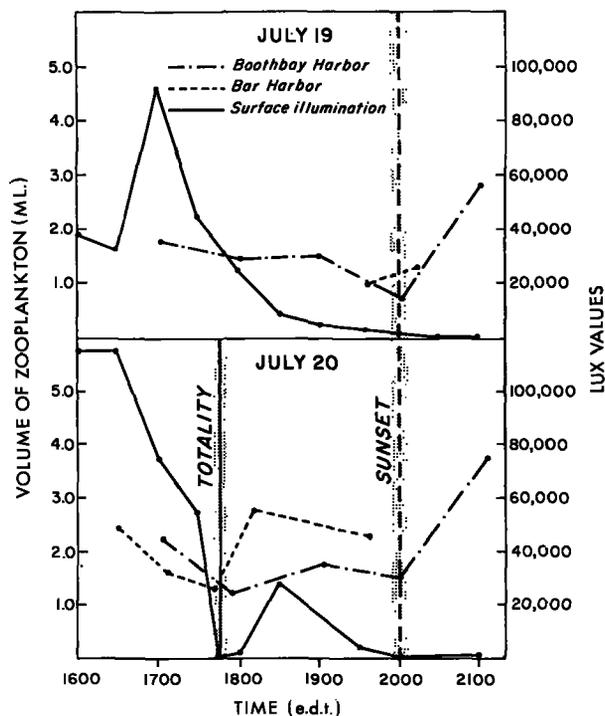


FIGURE 4.—Surface volumes of zooplankton from two sampling locations compared with surface illumination at Boothbay Harbor.

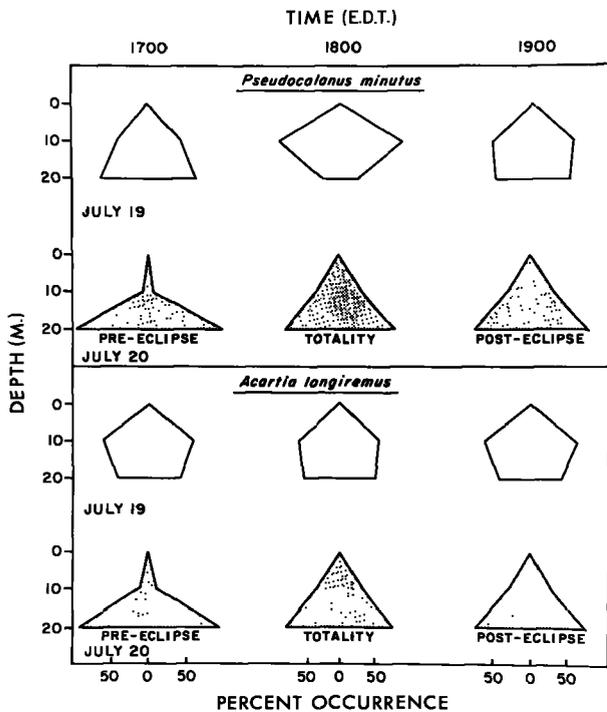


FIGURE 5.—Depth distribution of two species of copepods before, during, and after the eclipse.

forms, but showed no appreciable change in distribution during the eclipse. Though more frequent sampling might have established a basis for understanding these differences, it is evident that all species did not respond in the same degree or in the same manner.

The lack of uniformity among species and within species was not peculiar to the eclipse study. Wynne-Edwards (1962) summarized several early works which demonstrated the differences in behavior of copepods. Clark (1933 and 1934) discussed diurnal changes in vertical distribution relative to sex and age-groups and reported the stronger migratory habits of adult female *C. finmarchicus*, which rose much nearer to the surface at night than did the male. During the eclipse, female *A. longiremus* were more active than males and were more prevalent at the surface (fig. 6). There was a suggestion of a reversal of this phenomenon in *P. minutus*, and no difference in the distribution of sexes in *T. longicornis*. During the eclipse of 1954, Petipa (1955) reported that vertical migration in the Copepoda was

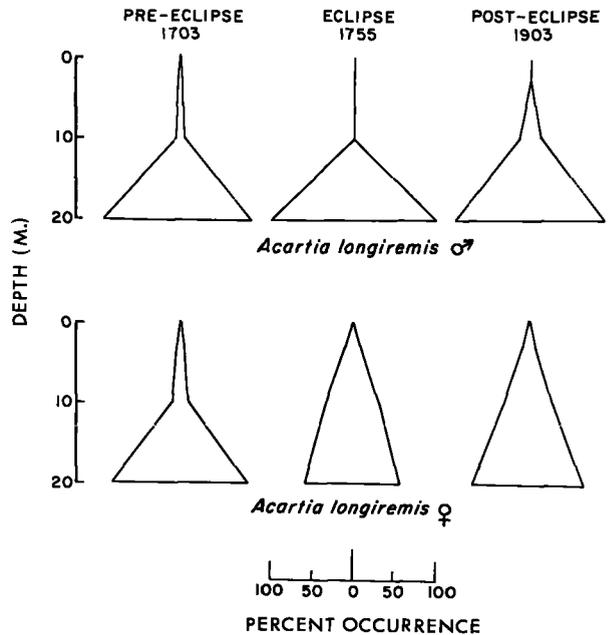


FIGURE 6.—Depth distribution in percent of male and female *Acartia longiremis* during the eclipse.

restricted almost entirely to adult females. In all of his samples, females of *A. clausi* were concentrated in the upper layers and the males at lower depths.

BEHAVIOR OF THE GREEN CRAB

Naylor (1958) observed that the rhythmic activity of green crabs (*Carcinus maenas*) could be divided into two components, one of diurnal frequency with a peak at night, and the other, a tidal frequency with a peak at high tide. On the day of the eclipse, low tide occurred an hour before totality and high tide three hours after sunset; consequently the behavior of the crabs could be judged independently of their response to tides.

Thirty crabs, 15 of each sex, were used as test animals. The mean width was 62 mm. (range, 42-79 mm.) for the males, and 60 mm. (range, 51-69 mm.) for the females. The males were banded so that the sexes could be readily distinguished during the experiment. The crabs were placed in a fiberglass tank 1.3 by 1.0 by 0.5 m. that had a 7-cm. layer of sand and gravel on the bottom (fig. 7). One corner of the tank was covered with fiberboard to provide a darkened shelter. Running water

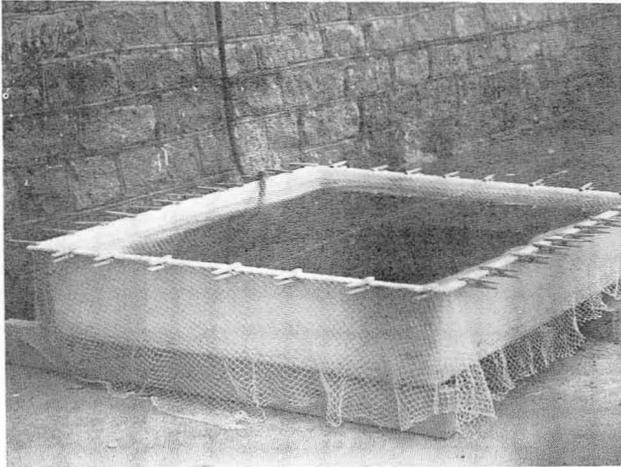


FIGURE 7.—Fiberglass tank for holding green crabs.

was supplied from the laboratory salt-water system and the tank was placed out-of-doors in an area free from shadows. Naylor (1958) found that the normal precision and level of the rhythmic activity declined after the crabs had been held for 3 to 4 days. For my study the crabs were placed in the tank two days before the eclipse and took refuge in the shelter immediately. Activity was recorded by counting the crabs that left this cover. A control was established by making observations periodically during the day before the eclipse and at 15-minute intervals from 1600 to 2200 hours, well past sunset.

On July 19 no crabs left the sheltered area until 2035. From that time until the last observation at 2205 the activity generally increased; as many as 11 males and 10 females left the covered area; the average number of active males was 5.7 and the average number of females 5.2. On the day of the eclipse, July 20, no activity was observed until 2050, more than 3 hours after totality; the greatest number of males in the unsheltered area at any time was 13, and the highest number of females 5; between 2050 and 2200 the average number of active males was 9.2 and females, 3.6.

Because the crabs were not active during the eclipse, other experiments were conducted the

following day to determine light conditions which would elicit a response. When the tank was in daylight (27,000 luxes) and then covered by a heavy tarpaulin that reduced the light to less than 10 luxes, 2 minutes elapsed before any activity was noted. Under conditions of subdued artificial light of 500 luxes, which was then reduced to less than 10 luxes, the response was more rapid; 3 crabs were active within 30 seconds and as many as 10 came out of the shelter within 2 minutes. As in the observations made on the date of the eclipse, the males were the first to respond. The light intensity in the half hour before totality was considerably greater than that of the artificial light; apparently the duration of subdued light during the eclipse was too short or the intensity too high to elicit a response from the crabs.

BEHAVIOR OF HERRING

Generally, the behavior of Atlantic herring (*Clupea harengus harengus*) is well documented, but specific responses are extremely variable. Blaxter and Parrish (1965), studying vertical movement, concluded that it was not possible to show any relationship between the preferred depth, or the extent of upward movement, and such factors as gradients of salinity, temperature, or food. The herring used in the eclipse study had been held in large tanks for several weeks. Though their behavior could not be considered comparable to that of herring in their natural environment, the fish were acclimated to confined conditions which were necessary for the observations made during the eclipse.

About 75 two-year-old herring were placed in a small-meshed holding pen during early morning of July 19. Observations were made at 15-minute intervals from 1600 to 2200 hours on July 19 and 20. The pen (dimensions, 3 by 3 by 2 m.) was visually separated into quadrants A, B, C, and D (fig. 8). Each quadrant was divided into two sections by an imaginary plane midway between the surface and the bottom of the pen. The presence or absence of fish in these quadrants and the depth divisions were recorded, along with remarks on schooling and directional movement. On both days, there

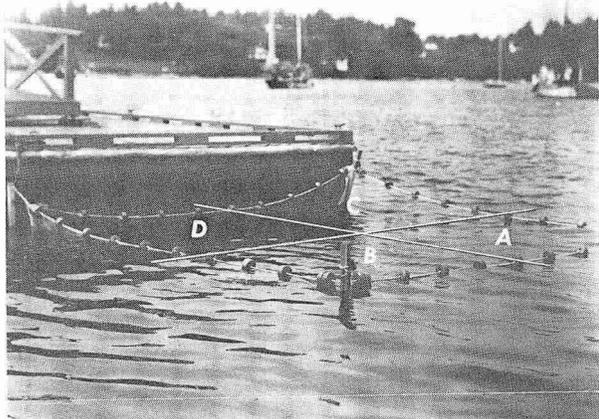


FIGURE 8.—Impoundment for herring, showing quadrants used to record observations.

was only one period (30 to 45 minutes) during which no fish were in the upper layer; this distribution occurred about an hour before sunset (2000). Similarly, there was only one period during which no fish were located in the lower layer. This period began one-half hour after sunset and continued for 45 to 60 minutes, after which herring were dispersed throughout the holding pen.

During daylight herring were more numerous in the upper area of quadrants A and B than in C and D. This difference probably is explained by the uneven distribution of light. Quadrants C and D were located closest to the vessel float which was used to anchor the holding net. The upper areas of these quadrants were shaded by the float and were avoided by the fish. The distribution of herring in the lower layers of A-B and C-D was relatively uniform. After dark, fish were equally dispersed in the upper and lower layers of the pen.

On the day of the eclipse, fish were distributed in the upper layers of quadrants A and B and in the lower layers of quadrants A, B, C, and D. Fish were absent from the upper layer of quadrant D until sunset. No fish were observed in the upper layer of quadrant C from the start of observations at 1600 until 1730—15 minutes before totality. Fish were active in this quadrant from 1730 until 1800; were absent at 1815; and reappeared from 1830 to 1900. This movement of fish into quadrant C at the approach of totality was coupled with a

change in behavior of herring in the other quadrants. Some fish began to school and moved to the surface of the water. This was in contrast to the preeclipse behavior of general dispersion without movement at the surface, and apparently was in response to the reduced light during the eclipse. The response was not strong, and not all fish reacted to the change. The data on subsurface illumination (mentioned above) suggests that the duration of lowered light intensity at totality was not enough to stimulate a stronger response. This conclusion is supported by the observations at sunset, when the decrease in light approximated that of the eclipse, but for a longer period, and elicited a stronger schooling response from the herring.

ECHO SOUNDINGS

Echo sounders aboard the two vessels were run continuously during the study, but none of the records showed any change or movement of organisms during the eclipse. Echo tracings in Boothbay Harbor documented considerable activity in the early evening on July 19 and 20 (fig. 9). On July 19, activity was first detected at 1854 when minor peaks and streaks extended up from the bottom. By 1955, some of these streaks and dots were no longer in contact with the bottom; others remained in contact but were extended and more pronounced. By 2100, only a few of these marks were in contact with the bottom; the rest were scattered from the bottom to the surface. This phenomenon was also recorded on the evening of July 20, though somewhat later and less pronounced than on the previous evening.

None of the organisms taken in the plankton nets was large enough to account for the markings observed on the recording paper, and the scheduled collections did not allow time to utilize other gear on July 19 or 20. On July 21, a trawl was fished during late evening in the same area. Echo soundings were similar to those on July 19 and 20. Large catches of jellyfish (*Aurelia aurita*) were taken in the net; presumably they were the animals detected by the sounder, but the possibility exists that the tracings were from herring or other fish that escaped capture. In any case, the lack

of response from these organisms during the eclipse indicated that the lowered light intensity or duration of totality, or both, were not sufficient to stimulate the kind of movement observed after dark.

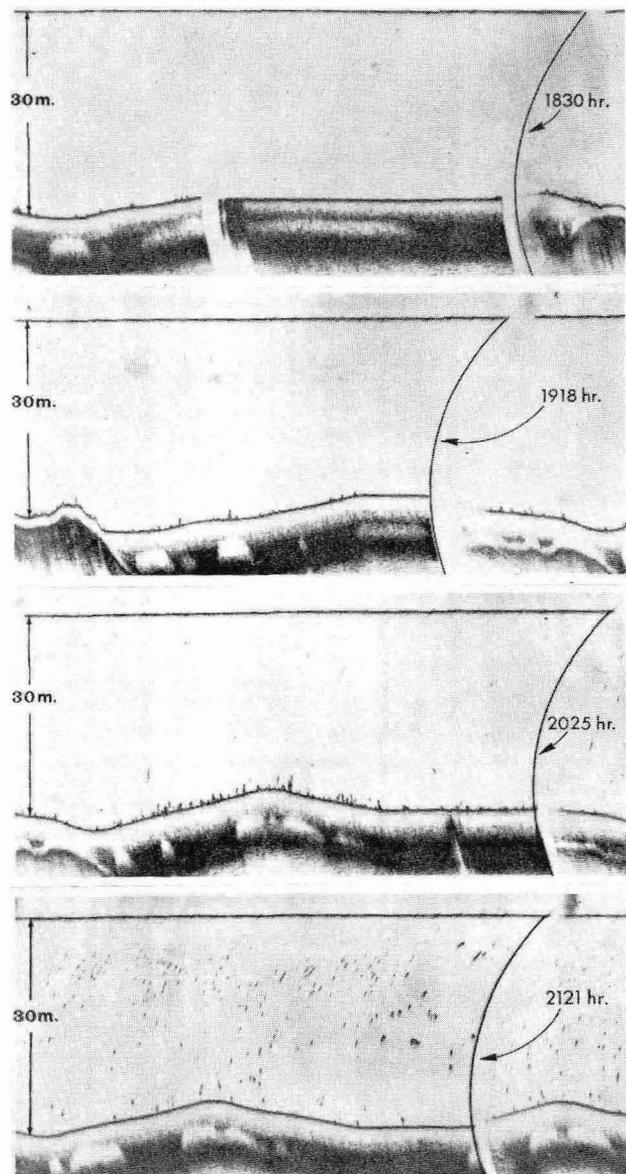


FIGURE 9.—Echo soundings before and after sunset (2000 hr.).

COMPARISON WITH OBSERVATIONS FROM OTHER ECLIPSES

The observations presented in this paper show some agreement with those of previous MARINE ORGANISMS DURING SOLAR ECLIPSE

workers, but the responses recorded for some species were not the same. Considering the variables such as light intensity, duration of totality, and the variation in experimental design, these differences are not surprising, but they should be equated.

Mori (1939) conducted carefully designed experiments on several species, and made detailed observation on others, including the sandhopper, *Orchestia* sp. He concluded that sandhoppers "were apparently not affected by the eclipse," yet he does mention that a few individuals were exposed "towards the end of totality . . .," exhibiting their normal crepuscular behavior, but this activity lasted only a few seconds before the animals retreated into hiding. Totality during the 1936 eclipse in Japan lasted 2 minutes, and began at 1519 when illuminance under normal conditions is high. As Mori stated, the inactivity may be explained by the fact that the change of light intensity at totality was too rapid; but he also cautioned that factors such as humidity and atmospheric pressure might have been the controlling influences. He also reported on observations from the aquarium of the Akkesi Marine Biological Laboratory, ". . . shrimp, a flat fish, a young salmon, a trout, and a herring were all indifferent to the eclipse, whereas a crab, which is quiet on ordinary days, began to move, and a bullhead appeared from the shady tangle of weeds when it became darker and hid again when it became lighter in just the same way as seen on ordinary days and nights."

In reference to light-dark cycles, Bünning (1964) stated that deviations from the natural frequency of an organism could "necessarily have an entirely different relationship to the light and dark period than normally. For example, if the dark period is too short, the organism with its own cycle length does not have time enough within the dark period to reach the usual physiological state typical of night." He also stressed that sometimes the beginning of the light period has a greater influence on the timing of responses during dark than the beginning of the dark period itself.

Other factors could also contribute to the degree of response. Of particular interest is the barometric pressure. As shown in figure 2, the pressure declined continuously for the 2 days preceding the 1963 eclipse. Brown (1958) showed that cycles of activity in certain organisms fluctuate with changes in pressure. These species included the fiddler crab (*Uca*), the oyster (*Ostrea*), and the quahog (*Venus*). Though these animals also exhibit daily and lunar cycles of activity, mean hourly rates of activity were correlated with the rates of rise or fall in barometric pressure. Activity increased with the hourly rate of fall and decreased with the rate of rise. The importance of this phenomenon to the observations during the 1963 eclipse is uncertain; it could be of significance during an eclipse with a relatively long period of totality.

In comparing the responses of zooplankton during the eclipses of 1954 and 1963, the importance of documenting the environmental differences is readily apparent. Petipa (1955) reported that most species reacted by rising to the upper water layer (0-5 m.) during the eclipse and by descending to lower depths (5-14 m.) after the eclipse. The strongest response was from *Sagitta*, and larvae of Decapoda, Lamellibranchia, and Gastropoda. His work was done in the Black Sea at Sevastopol Bay where surface temperatures during the eclipse (June) were at least 20° C. Zenkevitch (1963) described the general hydrological features of the Black Sea: salinity varied between 17 and 18 ‰ at the surface and was only 22 to 23 ‰ in deep water; temperature at 25 m. was 14° C. in summer and 6° C. in winter; dissolved oxygen content ranged from 1.05 to 7.76 cm.³/l. at 50 m. and declined rapidly with increasing depth below 50 m.; water deeper than 150 m. was contaminated with hydrogen sulphide; Secchi disks disappeared between 18 and 21 m.; and most species of zooplankton were found at depths above 50 m. and were concentrated between the surface and 25 m. Many of these characteristics are strikingly different from those in the coastal waters of the Gulf of Maine: during the eclipse of July 20 the temperature was less than 15° C. at the surface and was 10° C. at 10 m.; salinity was

about 32 ‰; and the Secchi disk disappeared at less than 10 m. The dissolved oxygen content in the Gulf of Maine was reported by Gran and Braarud (1935) to vary between 5.5 and 7.8 cm.³/l. at 40 m., and Bigelow (1926), in contrast to the conditions in the Black Sea, reported many species of zooplankton below 50 m., some of which had their densest concentrations below 100 m.

Other differences to consider include the characteristics of the eclipse and the location of sampling in relation to the path of totality. The sampling sites in Maine were selected because they lay in or near the path of totality. In contrast, Sevastopol Bay was about 400 miles from the path of totality in 1954. (This figure was estimated from eclipse data presented by Oppolzer, 1962.) As Petipa (1955) did not provide any measure of light intensity, one can only assume, other things being equal, that the illuminance during the eclipse was higher at Sevastopol than at Bar Harbor. Yet Petipa recorded more activity of zooplankton than was noted in the Gulf of Maine. Differences in species were important, but I suspect that the differences in the two environments were more critical.

Though not a species encountered in this study, experimentation on *Daphnia* offers several plausible explanations for the zooplankton behavior observed during the eclipse. Harris and Wolfe (1955) found that *Daphnia* responded rapidly to changes in light intensity, moving in the direction of the original optimum intensity, but this was followed by movement towards an adapted optimum and resulted in little change of position. In essence, a high change of intensity produced an alteration of photonegative and photopositive phases, and the net result had relatively little effect on the depth at which the animal was located. When changes in light intensity were slow, however, the animals simply followed the movement of the original optimum zone. Ringelberg (1964) disagreed with the explanation of the phototactic response offered by earlier workers; he concluded, on the basis of a very thorough laboratory and field study, "that the directing stimulus for the phototactic reaction is a contrast or a gradient present in the angular light

distribution." Schallek (1943) reported that *Acartia tonsa* in a glass cylinder would move upwards when illuminated from above and downward when illuminated obliquely. He considered the reaction of *A. tonsa* to diffuse light in the cylinder to be in accord with the downward movement in the ocean during the day, but that the reaction to direct light under experimental conditions had no bearing on its behavior in nature.

These experiments emphasize the importance of other variables that one must consider in attempting to compare and evaluate observations during an eclipse. The time of day and resultant attitude of the sun in relation to water clarity are of particular concern. Holmes (1957) discussed the penetration of water by light and explained that "The extinction of daylight in the sea is caused by absorption (by the water itself, by particles, and by dissolved substances) and by scattering (by the water and by particles)." Ringelberg (1964) and Schwassman and Hasler (1964) have recognized the importance of absorption and scattering on the phototactic behavior of aquatic organisms; the former paper referred to *Daphnia*, especially the orientation of the eye axis and the body axis, and the latter referred to sun orientation of fishes.

The responses of herring observed during the 1963 eclipse were in general agreement with reports of other observations under varying conditions of light intensity. Johnson (1939) studied captive herring in southern New Brunswick and concluded that, in the absence of direct sunlight, these fish "extended to the surface at all times—dawn, sunrise, cloudy days, sunset, dusk, moonlight, starlight, and cloudy nights." He also found that during daylight, the depth of the fish was greatest when the sun's altitude was highest and the largest fish were in the deepest water. Blaxter and Holliday (1963) summarized the work of European scientists, particularly in the North Sea where the diurnal migration pattern of herring is well documented; and the depth of herring shoals has been correlated with isolux lines to estimate the optimum depth for setting gill nets.

In studying diurnal changes in behavior of

adult herring, Blaxter and Parrish (1965) found that the depth (and light intensity) at which the fish occurred during the day was extremely variable; and demonstrated that fish did not move towards the surface until illuminance decreased to 10 luxes. These authors also reported that "recruit fish (2½–3 years old)" remained in higher light intensities by day. The eclipse study lends support to this latter conclusion. Though the response of 2-year-old herring at totality and at sunset was limited, the light intensity was above the level that Blaxter and Parrish observed as necessary to elicit a surface movement by adults. Breder (1951 and 1959) discussed the influence of light on the social grouping of many species of fish and provided a thorough summary of other scientists' work in this field. He stressed the differences in responses by individuals, by sex, and by species. This emphasizes the need to select species whose behavior patterns are well known, when attempting to evaluate the effects of a solar eclipse. The Atlantic herring, in this regard, is a suitable species, except that the sexes cannot be distinguished readily through external examination.

Mention should be made of the types of periodic activity and their importance to the observations made during the eclipse. Allee, Emerson, Park, Park, and Schmidt (1949) classified successive diel periods into two types: exogenous, "in which the pattern is directly induced and controlled by periodic environmental influences" and endogenous, "in which the pattern is resident in the organism." Aschoff (1960) elaborated on the definitions, explaining that an environmentally controlled periodicity (exogenous) will cease under artificially constant conditions; whereas, periodic factors of the environment only serve as synchronizing agents (Zeitgeber) for circadian or endogenous periodicity. He pointed out that a single environmental event can never synchronize continuously and therefore cannot operate as a Zeitgeber. This implies that observations made during an eclipse should not, of themselves, be used to determine whether a response or lack thereof is indicative of either an exogenous or endogenous rhythm. On the other hand, these observations can provide supporting evidence

for laboratory or other field experiments concerned with rhythmic behavior patterns. Cloudsley-Thompson (1961) cautioned that rhythmical activities of an animal are not necessarily all of one type and stated that rhythms solely dependent on the environment are rare and probably represent rhythms which are independent but out of phase with the environment. In regard to field observations during solar eclipses, he concluded that the results agree with those of laboratory experiments, in that certain animals exhibit some periodic activities that appear to be dependent on the environment and others that are more markedly independent.

SUMMARY

1. A total eclipse of the sun occurred in Maine on July 20, 1963. Totality lasted 59 seconds.

2. Biological and physical observations were made on the day before the eclipse and the day of the eclipse and were continued through sunset each day to provide a comparison with regular light-dark cycles.

3. Surface and subsurface illuminance declined markedly at totality, approximating conditions at sunset.

4. Barometric pressure declined steadily for the 2 days prior to the eclipse, reached a low point 29.45 mm. at totality, and then increased.

5. Zooplankton volumes from surface waters decreased during the eclipse and at sunset at both of the sampling areas.

6. Of the dominant copepods, *Pseudocalanus minutus* and *Acartia longiremis* exhibited the most pronounced response to the eclipse and moved toward the surface. The reactions of other species were either weak or ill-defined.

7. Female *Acartia longiremis* were more active than males during the eclipse, and moved toward the surface at totality.

8. No change was observed in the behavior of green crabs during the eclipse. Apparently, the duration of the eclipse was too short or the light intensity too high, or both, to elicit a response.

9. At totality, Atlantic herring held in a pen responded in a manner comparable to that observed at sunset. The response was not

strong, but some fish began schooling and moved into the surface waters.

10. Echo tracings documented a movement toward the surface after sunset, but tracings during the eclipse showed none of this activity. Though large catches of jellyfish were taken, the traces could have been made by fishes which escaped the net.

11. Comparisons of my observations with those made during other eclipses emphasize the importance of designing experiments carefully to assess properly the behavioral responses in relation to environmental changes.

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